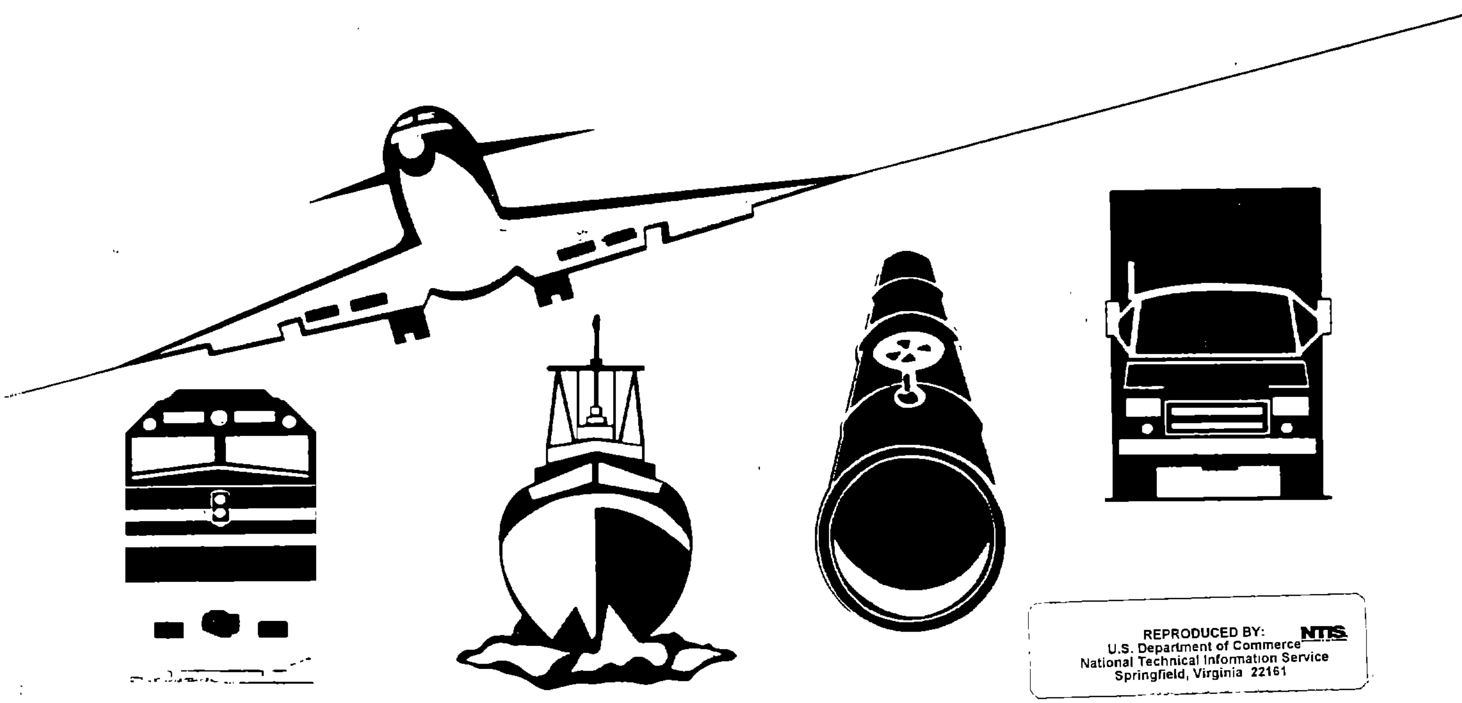
PB98-916604
NTSB/REC-98/04

PB98-916604

NATIONAL TRANSPORTATION SAFETY BOARD

TRANSPORTATION SAFETY RECOMMENDATIONS

ADOPTED DURING THE MONTH OF APRIL, 1998



TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NTSB/REC-98/04	2. Government Accession No. PB98-916604	3. Recipient's Catalog No.
4. Title and Subtitle Transportation Safety Recommendations Adopted during the month of April, 1998.		5. Report Date
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address National Transportation Safety Board Office of Safety Recommendations Washington, DC 20594		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address NATIONAL TRANSPORTATION SAFETY BOARD Washington, D. C. 20594		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This publication contains safety recommendations in aviation and pipeline modes of transportation adopted by the National Transportation Safety Board during the month of April, 1998.

AVIATION

A-98-34 through 39

PIPELINE

P-98-1 through 5
P-98-6
P-98-7 through 9
P-98-10
P-98-11 and 12
P-98-13
P-98-14 and 15
P-98-16 and 17
P-98-18

PIPELINE (Cont.)

P-98-19
P-98-20

17. Key Words		18. Distribution Statement	
19. Security Classification (of this report) UNCLASSIFIED	20. Security Classification (of this page) UNCLASSIFIED	21. No. of Pages 66	22. Price

NTSB Form 1765.2 (Rev. 9/74)

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 7, 1998

In reply refer to: A-98-34 through -39

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 17, 1996, about 2031 eastern daylight time, a Boeing 747-131, N93119, operated as Trans World Airlines (TWA) flight 800, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport, Jamaica, New York. All 230 people aboard the airplane were killed. The airplane, which was operated under Title 14 Code of Federal Regulations (CFR) Part 121, was bound for Charles De Gaulle International Airport, Paris, France. The flight data recorder and cockpit voice recorder ended simultaneously, about 12 minutes after takeoff. Evidence indicates that as the airplane was climbing near 13,800 feet mean sea level, an in-flight explosion occurred in the center wing fuel tank (CWT), which was nearly empty.

The source of ignition of the CWT has not been determined, and the investigation into a variety of potential ignition sources continues. However, the Safety Board's investigation has found damaged wiring in the fuel quantity indication systems (FQIS)[1, 2] of the accident airplane

[1] The B-747 FQIS measures fuel quantity with a capacitance measurement fuel probe system in each fuel tank. There are seven capacitance measurement fuel probes in the B-747 CWT. Each fuel probe consists of an inner tubular element that is surrounded by an outer tube. Compensators, located near the low point of each fuel tank, are also constructed of assemblies of tubular elements. The compensators and probes have a hard plastic terminal block near the top of each to provide for wiring connections. Wires from each fuel probe and the compensator are routed within the fuel tank through nylon clips to a connector located at the rear wing spar and are exposed to fuel and vapor.

[2] Most of the B-747-100, -200, and -300 series airplanes (about 700 airplanes) are equipped with FQIS manufactured by Honeywell Corporation; airplanes equipped with the Honeywell system are the subject of this letter. About 10 percent of the B-747-100, -200, and -300 series fleet has been retrofitted with FQIS manufactured by BFGoodrich Aerospace Corporation (formerly Simmonds Precision). The B-747-400 series airplanes are equipped with the BFGoodrich system equipment. No BFGoodrich FQIS were inspected during the investigation.

and three retired B-747s: N93105[3] and N93117[4] and a former Air France airplane, F-BPVE,[5] and the Safety Board was informed of damaged FQIS wiring in a British Airways B-747, G-BBPU.[6] These findings illustrate unsafe conditions that may exist in other B-747s and should be addressed by the Federal Aviation Administration (FAA).

The potential hazardous features found inside of B-747 fuel tanks during the investigation include the following:

1. FQIS wire insulation had been damaged near the attachment point of wires to four CWT fuel probe and compensator terminal blocks in N93105.[7] Terminal blocks with knurled (rough) areas on the surface had Honeywell Corporation manufacturing dates of November 1970[8] and earlier and were identified as Series 1, 2, and 3.[9] These terminal blocks had a metal strain relief clamp pressing the FQIS wires against the knurling. The knurled area consisted of a series of relatively sharp pointed cones in the hard plastic, and the edges of the terminal block castings transected the cones, thus creating sharp edges resembling saw teeth. The FQIS wire insulation had been cut by the knurled area, exposing the core conductors of some wires to the grounded shielding of others.[10]

---

[3] N93105 had been undergoing maintenance when it was retired from service by TWA in 1994. The airplane had been in storage in Kansas City since that time.

[4] N93117 had been sold by TWA in 1992, and was subsequently placed in storage in Mojave, California, after 77,145 flight hours.

[5] F-BPVE was retired by Air France in September 1994. The airplane was subsequently used by the Safety Board and other agencies for testing in Bruntingthorpe, England.

[6] G-BBPU is an in-service B-747-136. At the time of its inspection on November 1, 1996, the airplane had been operated 89,639 hours and 17,437 cycles since new.

[7] Few terminal blocks from N93119 were recovered and most of those were fragmented or otherwise damaged. Although few of the fragments had attached FQIS wires, chemical traces on the exterior of damaged wire insulation had been deposited on and around previously damaged surfaces. Damage similar to that found in N93105 has been seen in some FQIS components from F-BPVE.

[8] On May 28, 1969, Boeing implemented a requirement for the wires to withstand a 50-pound pull, and on December 29, 1969, Honeywell Engineering Change Order 69 15826 revised the design to a Series 4 terminal block, which deleted the use of screws to fasten FQIS wires to the terminal block and introduced the use of threaded studs and nuts. On the Series 4 block, the metal strain relief clamp and knurling were deleted and the FQIS wires were held within the eye of a "P"-shaped nylon clamp that held the wiring above the terminal block surface. The change order was to be effective as soon as new terminal blocks were available. Boeing reported that a production change was made at Boeing that installed the Series 4 terminal blocks in [airplane] line number 65 and onward. Since N93119 was line number 153 and was delivered on October 27, 1971, Boeing concluded that it was improbable that it was delivered with Series 3 terminal block probes. A mixture of terminal block series that included Series 1-3 and subsequent designs were found in each of the cited B-747 airplanes, including N93119.

[9] The Honeywell Component Maintenance Manual still shows the Series 1-3 terminal blocks and metal strain relief clamps as "applicable" [acceptable] for use. Honeywell has reportedly supplied them as replacement parts, although only the updated design is now sold.

[10] Wire shielding covers the inner insulation and core conductor with a layer of woven wire, which isolates the conductor from electromagnetic signals and provides protection to the inner insulation and core conductor from external mechanical damage. Additional insulation covers the wire shielding.

2. In addition to the knurled surfaces found in the Series 1-3 fuel probes, B-747 fuel probe terminal blocks and compensators have squared edges that can damage wire insulation. A wire that had been located against the edge of a Series 1-3 terminal block from N93105 had a lengthwise cut in its insulation. (In contrast to the B-747 Series 1-3 terminal blocks, Honeywell also makes B-757 and B-767 fuel probes with terminal block edges that are smooth and rounded.)

3. The insulation of a fuel probe wire from the CWT in N93105 was also found to be displaced (cold-flowed), exposing its core conductor. The wire had been one of several pressed under the strain relief clamp of a Series 1-3 fuel probe terminal block. Wire insulation was also displaced by cold-flow or chafe at points of tight contact between wires not under the knurled clamps and where wires were pressed against plastic heat-shrink material on adjacent wires, in some instances exposing the conductor of one wire to the shield of a second wire. Displaced insulation that had been damaged but not breached was identified at various locations where wires pressed against other wires, where wires were in contact with the edge of a clamp, and at the edges of nylon clips where the FQIS wire routing made sharp turns inside the fuel tanks. Points of chafing and potential chafing were also found where FQIS wires contacted structure in the CWT of N93117.

4. During the accident investigation, two inappropriate repairs were found in the FQIS wiring in the wing tip fuel tanks of the accident airplane and another inappropriate repair was found by Boeing in a B-747 operated by another airline. The shielding of an N93119 wingtip tank FQIS probe wire had been previously broken and repaired. The repair of the wire consisted of splicing with a crimped connector and covering it with adhesive tape secured by wire bundle lacing tape.[11] Although the repair was functional, separated wire strands were found at the edge of the crimped connector. The separated strands had flat and angled-surface features, indicative of a fatigue failure. Boeing recommends that such broken FQIS wire be removed, solder-repaired, and covered with heat-shrink tubing. The second inappropriate repair found in N93119 was on a post-Series 3 compensator, where an oversized terminal block strain relief "P-clamp" had been used. The replacement P-clamp was larger than specified and unable to grip the FQIS wire harness. To provide strain relief. the wire harness had been looped to pass through the clamp twice and was still a loose fit. The third inappropriate repair was found in the CWT

[11] Wiring in B-747s is assembled into harnesses with lacing tape made of Dacron, fiberglass, or Nomex, as specified in the Boeing Standard Wiring Practices Manual, section 20-00-11, page 17, Table XX, "Tie Materials."

of G-BBPU, where chafed FQIS wires had been repaired with fuel tank sealant.[12]

The damaged wiring at the terminal blocks was found only after the wiring had been removed. A close visual inspection in the tank without removing the wires would have been insufficient to disclose damage that is concealed between wires or under wire clamps. These types of damage could create spark gaps that are very small and that could become latent failures in the wiring system.

Boeing issued Service Bulletin (SB) 747-28-2205 on June 27, 1997, and a notice of status change for this SB on September 25, 1997, to address B-747 fuel tank inspection procedures. However, the recommended inspection procedures for FQIS wires, fuel probes, and compensators were not addressed in sufficient depth for operators to find wire insulation damage similar to that found during the TWA 800 accident investigation. Most of the damaged FQIS wire insulation found during the accident investigation was concealed beneath strain relief clamps or other wires and was discovered only after the wiring was removed from terminal blocks. In some cases, the damage was not apparent until the ends of the wires were inspected under magnification.

On October 27, 1997, Boeing issued a notice to B-747 operators (M-7220-97-1725) describing a planned SB that would provide further details on inspecting B-747 fuel probes, compensators, and FQIS wires. In an October 30, 1997, letter to the Safety Board, Boeing stated that the new SB will recommend the replacement of Series 1-3 fuel probes, the reporting of damage involving Series 4 and later fuel probes, the replacement of certain CWT FQIS wire harnesses, and the inspection for proper wire routing and existing damage; the SB will also establish an electrical resistance check of very low voltage and establish standards for FQIS repairs.

The Safety Board appreciates Boeing's efforts to develop a new SB to improve inspection of B-747 CWT FQIS components. However, compliance with SBs is not mandatory. The Safety Board believes that the FAA should issue, as soon as possible, an airworthiness directive (AD) to require a detailed inspection of FQIS wiring in B-747-100, -200, and -300 series airplane fuel tanks for damage, and the replacement or the repair of any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination.

In December 1969, Boeing reportedly discontinued using the Honeywell Corporation Series 1-3 fuel probes (with knurled terminal block surfaces and metal strain relief clamps) and began using the Series 4 (and later) fuel probes[13] as a product improvement. However, the change was not considered mandatory and Series 1-3 fuel probes are still found in airplanes. This investigation has shown that the knurling and the sharp edges of the early design terminal

---

[12] The Boeing Standard Wiring Practices Manual describes methods and materials that can be used for wire repairs. It does not list fuel tank sealant as an approved material for repair of electrical wiring.

[13] See footnote 7.

blocks create damage to wire insulation. Changing to a Series 4 terminal block reduced the potential for FQIS wires to be damaged by the terminal blocks. However, the Honeywell overhaul manual still shows the Honeywell Series 1-3 terminal blocks as "applicable for use." The Safety Board believes that the FAA should issue an AD to require the earliest possible replacement of the Honeywell Corporation Series 1-3 terminal blocks used on B-747 fuel probes with terminal blocks that do not have knurled surfaces or sharp edges that may damage FQIS wiring.

Features of the fuel probes and wiring installation used in B-747s are similar to those of Honeywell fuel probes used in other airplanes, including the B-707, Lockheed C-130, B-757, and B-767. The B-707 and C-130 terminal blocks have a different shape but have some features similar to the B-747 design, including sharp edges. The B-757 and B-767 fuel probe terminal blocks have rounded edges and cast wire relief areas that are not used in the B-747 terminal blocks; the FQIS wires are retained in the cast wire relief areas by a flat metal bar. Wiring attached to the terminal blocks in airplanes other than the B-747 has not been examined by the Safety Board staff during the TWA 800 investigation. However, because of the similarities found during a review of fuel probe designs, the Safety Board is concerned that FQIS wiring problems discovered in this investigation may also exist in other airplanes with similar designs. Therefore, the Safety Board believes that the FAA should conduct a survey of FQIS probes and wires in B-747s equipped with systems other than Honeywell Series 1-3 probes and compensators and in other model airplanes that are used in 14 CFR Part 121 service to determine whether potential fuel tank ignition sources exist that are similar to those found in the B-747. The survey should include removing wires from fuel probes and examining the wires for damage. Repair or replacement procedures for any damaged wires that are found should be developed.[14]

Dark deposits were found around the wiring connections of fuel probes that had been removed from various fuel tanks in N93105, N93117, N93119, and F-BPVE. The deposits were found on wire insulation and on numerous plastic sleeves of crimped wire splices. A scanning electron microscope revealed that the dark deposits on N93119 and N93105 fuel probes contained copper, silver (silver-plated copper wiring is used in fuel tanks), and sulfur (a contaminant in jet fuel). The deposits on an N93119 FQIS compensator fragment were further examined at a U.S. Air Force research laboratory (Wright Laboratory) and were determined to be similar to copper sulfide deposits found in previous examinations of fuel probes from military aircraft. The laboratory had previously found that the deposits gradually reduced resistance between electrical connections of the military airplane fuel probes.

Wright Laboratory staff received a fuel probe that had been removed from a military trainer and tested at a maintenance depot while the probe was still wet with fuel. The test involved voltage and current levels greater than those that would be available from the FQIS. According to the Wright Laboratory staff, disassembly of the probe revealed soot and carbonized copper-sulfide deposits, apparently from the ignition of fuel vapors. A report by the Wright

---

[14] Boeing is currently conducting a survey of Honeywell Series 4 probes and compensators.

Laboratory[15] states that a subsequent visual inspection found "discoloration and possible arcing on the bottom" of the probe. The report stated further, "It appears the internal probe wires were damaged by a fire. Evidence of an electrical arc was evident on the nylon cap which would have provided the required energy needed to ignite residual fuel." Another fuel probe documented by the same set of reports had evidence of an arc-track[16] with deposits composed of copper sulfide and carbon. Unburned deposits that were photographed by a scanning electron microscope had the appearance of flaking paint. Electronic testing for the resistance value of similar deposits on a third fuel probe revealed "small scintillating arcs" between the flakes, as current was increased to 5 milliamperes (voltage unknown) between a set of probes located 10 millimeters apart. When drops of JP-4 fuel were placed on the arcing deposit, the report said, "heat generated by the [electric] current rapidly evaporated the fuel. Resistance increased from 13,200 ohms to an open circuit (>20M)[17] after a few seconds." The flaking copper sulfide deposits were found to be a brittle substance that clung tenaciously to plastic materials and could only be cleaned by mechanical abrasion. The report concluded the following:

> The residues act as a thin film resistor that will rupture and open if significant current is passed through the material. Residue formation is most likely the result of a long-term degradation or corrosion process. Exposed silver plated copper wiring and other silver containing surfaces (electrodes) are apparently reacting with the sulfur in the fuel. This deterioration process is most likely time dependent and, as the probes age, more probe [calibration] failures can be expected.

Copper sulfide deposits were found inside the FQIS wire insulation of N93105 and N93119, where the wires had damaged insulation. The Safety Board is concerned that copper sulfide deposits on FQIS wires could become ignition sources in B-747 and similarly designed fuel tanks. The Safety Board believes that the FAA should require research into copper-sulfide deposits on FQIS parts in fuel tanks to determine the levels of deposits that may be hazardous, how to inspect and clean the deposits, and when to replace the components.

The investigation has also found that although the design for the B-747 CWT FQIS provides for limited electrical power in the fuel tank,[18] the FQIS wires are routed in bundles with nearly 400 other wires, some of which carry up to 350 volts.[19] The FQIS harness routed between

---

[15] Wright Laboratory Report "Analysis of Trainer Aircraft Fuel Probes I," dated March 1990, by George Slenski, Materials Integrity Branch, Systems Support Division, Materials Directorate.

[16] Arc-tracking is an insulation failure leading to flashover. Tracks develop along the discharge path on the surface of the insulation. The tracks are generally more conductive than the virgin insulation. These tracks carbonize quickly into significant conducting paths.

[17] Mega-ohms are one million ohms of electrical resistance.

[18] Power to the FQIS is limited by Boeing to 0.02 millijoules, or less than 10 percent of minimum ignition energy (MIE) required to ignite Jet A fuel under laboratory conditions, according to the American Petroleum Institute Recommended Practice 2003, Fifth Edition, December 1991, entitled "Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents."

[19] Zone A ceiling light wire W-1306-L1892-22 carries up to 350 volts. Numerous other wires carry 115 volts alternating current (VAC) and 28 volts direct current and are routed in bundles with FQIS system wires. Boeing

the CWT and the flight engineer's panel in the cockpit contains one shielded wire and two unshielded wires in a woven fiberglass sleeve. Boeing noted in an October 27, 1997, letter that this is a common design for capacitive FQIS systems. Behind the flight engineer's panel, the sleeved set of Teflon-insulated FQIS wires was connected to unprotected[20] general airplane wiring[21] that was routed to the fuel totalizer indicator and to the electrical/equipment (E/E) compartment located beneath the forward cabin and behind the nose landing gear. Additionally, unshielded Teflon wiring from the right wing fuel tanks was attached to a terminal strip located on spanwise beam No. 2 in the CWT, then was routed through the left wing fuel tanks to the ground refueling panel gauges located between the Nos. 1 and 2 engines. At the ground refueling panel, the fuel tank wiring was routed with other aircraft wiring for the refueling indicators and controls.

Electrical short circuits can introduce high voltage into low voltage conductors. For example, it was determined that a military C-130 fuel tank exploded in the 1970s after improper maintenance had created a short circuit within a fuel gauge electrical connector.[22] Maintenance work on the connector was not finished before the flight, and the investigation found that 115 VAC power was inadvertently allowed to enter the fuel tank through the shielding of FQIS wires.

In the investigation of a May 11, 1990, Philippine Airlines B-737-300 CWT explosion at Ninoy Aquino International Airport, Manila, Philippines, the exact source of ignition was never established. However, the Safety Board later concluded, "It is possible that the combination of a faulty float switch and damaged wires providing a continuous power supply to the float switch may have caused an electrical arc or overheating of the switch leading to the ignition of the center fuel tank vapor."[23]

An Air Force study[24] of data from 1986 to 1989 mishaps[25] caused by electrical failures found 652 records, of which 326 were examined in detail. Of the 326 reports, 49 involved "conductors" (typically aircraft wiring) and 51 involved "connectors" of numerous types. The study concluded the following:

RA164 Center Wing Tank Wire Bundle Analysis Report, December 17, 1996, indicates bundle No. W186 contains 12 192-volt wires for the flight engineer panel lighting.

[20] Wires that were not isolated or shielded and that were routed in bundles with other wires, some of which carried power for other airplane systems.

[21] Wire markings identified the general N93119 aircraft wiring as (Boeing Specification) BMS13-42A, marketed by Raychem. The wire was sold commercially under the trade name "Poly-X." Other types of wire were also used in the construction of B-747 airplanes.

[22] The Safety Board was permitted to review a report regarding a military C-130 fuel tank explosion that occurred after improper maintenance created a short circuit that created an ignition source in the fuel tank. The airplane identification and the date and location of the incident have not been released.

[23] National Transportation Safety Board. August 1, 1990. Safety Recommendations A-90-100 through -103.

[24] Contract F33615-89-C-5647, completed January 1989, to develop a handbook for the evaluation of electrical components in aircraft accident investigations.

[25] According to the Air Force, there are four classes of mishaps in the Norton database [of USAF mishaps]. Classes A, B, and C generally represent in-flight conditions that result in some damage to the aircraft. The fourth class includes potential mishaps, which may be the result of unusual conditions observed during maintenance or preflight checks.

> The majority of aircraft mishaps involving electronics are related to interconnection problems. Interconnection problems are primarily due to wiring and connector failures. Chafing, which results in electrical arcing of wiring, and corrosion, which results in the electrical breakdown in connectors, appear to be the dominate failure mechanisms.

Such findings are not unique to military mishaps. For example, on July 19, 1997, a Lufthansa B-747 freighter (D-ABZC) was on final approach to JFK International Airport, New York, when seven circuit breakers popped in the cockpit. Afterward, maintenance personnel found 47 (non-FQIS) wires burned in more than 8 inches of the affected wire bundle; the wires were located beneath the oxygen bottles in the "cheek" area to the right of the forward cargo compartment. The wires led to the leading and trailing edge flaps, landing gear circuitry, and the anticollision lights. Circuitry for the wing flap asymmetry detection and a flap electrical drive motor led to the burned area, and each of those components needed replacement. The airplane had been purchased from another carrier and, in April 1993, was modified by a third company to the freighter configuration. Lufthansa found that this airplane and five others that were modified by the same company had metal drill shavings and other debris in that area of the wire bundle. The incident demonstrated the danger of allowing metal shavings to remain on wiring and the possibility of introducing enough electrical energy into unrelated circuits to damage electrical components.

In addition to investigating the potential for introducing energy into FQIS wires from direct short circuits, tests were conducted to determine the energy that can be induced into unshielded FQIS wires by electromagnetic inductance (EMI). Laboratory tests[26] have shown that EMI can introduce elevated levels of energy into FQIS wiring, and sparks can be induced by adding foreign material to the fuel probes, thus creating spark gaps. This amount of energy was only found during tests in which a spark gap was artificially created between the Lo-Z (outer fuel probe electrode or terminal) and ground. To date, testing has not duplicated those results on an airplane. The investigation of this issue is continuing.

Wire shielding and physical separation each provide EMI and chafe protection for the inner conductor and a path to ground for short circuits from other wires and are widely used in airplanes. However, two of the three recovered FQIS wires from N93119 that had been routed between the CWT and the cockpit in a woven sleeve were not protected from EMI or chafing by shielding or separation from other wires. Also, BMS13-42A wires that were found routed from the cockpit end of the FQIS harness to the E/E compartment were not shielded or separated. In 1974, Boeing incorporated an overall shield around all three CWT FQIS wires routed between the CWT and flight engineer panel; in 1980, Boeing added further shielding to FQIS wires behind the flight engineer panel. However, these wiring changes were not required for previously manufactured airplanes, such as N93119. In its October 27, 1997, letter, Boeing

[26] Tests were conducted to Boeing specification to create transient voltages and sparks by switching electrical power on and off in wires that had been laid parallel to the CWT bundle. Tests induced up to 0.060 millijoules of energy in the CWT harness, exceeding the API practice 2003 reference for an MIE requirement of 0.025 millijoules.

acknowledged the additional benefits of shielding, but wrote that the shielded wire was used to correct for electrical noise in the FQIS wires (not for EMI or chafe protection).

The Safety Board recognizes the difficulty and expense associated with physically separating FQIS wires from other wires and adding shielding to FQIS wires on in-service air carrier airplanes. Access is limited behind avionic racks and at bulkhead electrical connectors, and rewiring is labor intensive. However, the separation of the FQIS from other power sources by shielding and separation can protect fuel tank wires from power sources that can potentially ignite an explosive vapor in a fuel tank. The Safety Board believes that the FAA should require in B-747 airplanes, and in other airplanes with FQIS wire installations that are corouted with wires that may be powered, the physical separation and electrical shielding of FQIS wires to the maximum extent possible.

Because of the variety of latent potential ignition sources found in B-747 fuel tanks, and the variety of means by which energy can be introduced into FQIS wires, the Safety Board does not believe that correcting wiring deficiencies and addressing system failures would fully protect the B-747 CWT and other fuel tanks against all potential ignition sources. Total FQIS wire shielding or separation from other wires would be very difficult to change in airplanes already in service and would not address failures within system components, such as fuel gauges, ground refueling volumetric shutoffs, and data acquisition units. Unless the volatility of fuel tank vapors can be eliminated as a potential hazard, electrical power surge suppressers may be the most effective method of preventing the FQIS from becoming an ignition source. On December 1, 1997, the FAA issued a notice of proposed rulemaking applicable to B-747-100, -200, and -300 series airplanes that agreed with this premise and would require either the installation of components for the suppression of electrical transients by electromagnetic interference, or the shielding and separation of the electrical wiring of the FQIS.

Surge suppressors installed where FQIS wires enter fuel tanks could provide added protection against excessive power surges in the FQIS system, regardless of origin. Surge protection systems are used in a range of devices, from autopilots to personal computers. Boeing has successfully used electrical surge suppression in other applications, but has noted that extreme care would have to be used in an FQIS application to account for possible influences on system operation and failure modes. Because the basic concepts of most capacitance FQIS systems are similar, the Safety Board believes that the FAA should require, in all applicable transport airplane fuel tanks, surge protection systems to prevent electrical power surges from entering fuel tanks through FQIS wires.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Issue, as soon as possible, an airworthiness directive to require a detailed inspection of fuel quantity indication system wiring in Boeing 747-100, -200, and -300 series airplane fuel tanks for damage, and the replacement or the repair of

any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination. (A-98-34)

Issue an airworthiness directive to require the earliest possible replacement of the Honeywell Corporation Series 1-3 terminal blocks used on Boeing 747 fuel probes with terminal blocks that do not have knurled surfaces or sharp edges that may damage fuel quantity indication system wiring. (A-98-35)

Conduct a survey of fuel quantity indication system probes and wires in Boeing 747s equipped with systems other than Honeywell Series 1-3 probes and compensators and in other model airplanes that are used in Title 14 Code of Federal Regulations Part 121 service to determine whether potential fuel tank ignition sources exist that are similar to those found in the Boeing 747. The survey should include removing wires from fuel probes and examining the wires for damage. Repair or replacement procedures for any damaged wires that are found should be developed. (A-98-36)

Require research into copper-sulfide deposits on fuel quantity indication system parts in fuel tanks to determine the levels of deposits that may be hazardous, how to inspect and clean the deposits, and when to replace the components. (A-98-37)

Require in Boeing 747 airplanes, and in other airplanes with fuel quantity indication system (FQIS) wire installations that are corouted with wires that may be powered, the physical separation and electrical shielding of FQIS wires to the maximum extent possible. (A-98-38)

Require, in all applicable transport airplane fuel tanks, surge protection systems to prevent electrical power surges from entering fuel tanks though fuel quantity indication system wires. (A-98-39)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-1 through -5

Ms. Kelley Coyner
Acting Administrator
Research and Special Programs Administration
400 7th Street, S.W.
Washington, D.C. 20590

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by RSPA. The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

service line to a plastic main.[4] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[5] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[6] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[7] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[8] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[9] The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged

---

[4]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[5]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[6]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[7]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[8]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[9]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

automobiles.[10] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[11] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[12] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[13]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[14] The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

Excavations following the Waterloo, Iowa, accident uncovered, at a depth of about 3 feet, a 4-inch steel main.[15] Welded to the top of the main was a steel tapping tee. Connected to the steel tee was a 1/2-inch plastic service pipe. Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred

---

[10]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[11]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[12]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[13]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[14]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

[15]For more information, see Pipeline Accident Brief in appendix to National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service.*

between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate a greater susceptibility to brittle-like cracking under the test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[16] characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking. The Safety Board has investigated two other pipelines accidents, one in Nebraska in 1978 and one in Minnesota in 1983, that involved Century piping. The Safety Board is also aware of four other accidents that it did not investigate that involved the same brand of piping.

The Century pipe involved in the Waterloo accident was made from Union Carbide's DHDA 2077 Tan resin. Although Union Carbide's laboratory data supported Union Carbide's claimed strength, the Safety Board's review of the same data showed that the material had an early ductile-to-brittle transition, indicating poor resistance to brittle-like fractures.

In the early 1970s, a Minnesota gas system operator tested a number of piping products made from DHDA 2077 Tan resin, including those marketed by Century, as part of its comprehensive specification, testing, and evaluation program. The company rejected piping made from the Union Carbide product for use in its system based on the results of sustained pressure tests. Union Carbide, in 1971, acknowledged that its DHDA 2077 Tan resin material had a lower pressure rating at 100 °F than did DuPont's polyethylene pipe material.

Midwest Gas, the Waterloo, Iowa, gas operator at the time of the explosion and fire, had experienced at least three other significant failures involving Century pipe. The most recent failures, occurring between 1992 and 1994, prompted the company to collect samples of the Century material for independent laboratory testing. Samples were being gathered for testing at the time of the Waterloo accident. The subsequent laboratory report indicated that the Century piping had poor resistance to slow crack growth.

Midwest Gas's subsequent analysis of the company's leakage history concluded that its installations with Century piping had failure rates significantly higher than those with piping

---

[16]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981; Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1*, Gas Research Institute Report No. 84/0235.2, 1989; and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings, Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp. 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

from other manufacturers. Midwest Gas had received warnings from two pipe fitting manufacturers against use of their products with Century pipe because of Century pipe's susceptibility to brittle-like cracking. The current operating company in the Waterloo, Iowa, area, MidAmerican Energy, has, since the accident, replaced all the identified Century piping in its gas pipeline system.

The Safety Board concluded that plastic pipe extruded by Century Utility Products, Inc., and made from Union Carbide's DHDA 2077 Tan resin has poor resistance to brittle-like cracking under stress intensification, and this characteristic contributed to the Waterloo, Iowa, accident.

While Century piping has been identified specifically as being subject to brittle-like cracking (slow crack growth), evidence suggests that much of the early polyethylene piping may be more susceptible to such cracking than originally thought and thus may also be subject to premature failure.

The procedure used in the United States to rate the strength of plastic pipe, which was developed in the early 1960s, involved subjecting test piping to different stress values and recording how much time elapsed before the piping ruptured. The stress rupture data of the samples were then plotted, and a best-fit straight line was derived to represent the material's decline in rupture resistance as its time under stress increased.

To meet the requirements of the procedure, at least one tested sample had to be able to withstand stress rupture testing until at least 10,000 hours, or slightly more than 1 year. The straight line that was plotted to describe the data for this material was extrapolated out by a factor of 10, to 100,000 hours (about 11 years). The point at which the sloping straight line intersected the 100,000-hour point indicated the appropriate hydrostatic design basis for this material.

A key assumption characterized the assignment of a hydrostatic design basis under the procedure: The procedure assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would continue to be described by a straight line. In the early 1960s, the industry had little long-term experience with plastic piping, and a straight line seemed to represent the response of the material to laboratory stress testing. With little other information on which to base strength estimations, the straight-line assumption appeared valid. This procedure and assumption for rating the strength were incorporated into industry and government requirements.

As experience grew with plastic piping materials and as better testing methods were developed, however, the straight-line assumptions of the procedure came to be challenged. Elevated-temperature testing indicated that polyethylene piping can exhibit a decline in strength that does not follow the straight-line assumption, but instead shows a downturn. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours.

The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping much more reliable.

Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concluded that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

Another important assumption of the design protocol for plastic pipe involved the ductility of the materials. It was assumed, based on short-term tests, that plastic piping had long-term ductile properties. Ductile material, by bending, expanding, or flexing, can redistribute stress concentrations better than can brittle material, such as cast iron. Notable from results of tests performed under the strength-rating procedure was that those short-term stress ruptures in the testing process tended to be characterized by substantial material deformation in the area of the rupture. This deformation described a material with obvious ductile properties. However, it was shown that, as time-to-failure increased in stress rupture tests, failures in several materials occurred as slit failures that, because they were not accompanied by substantial deformation, were more typical of brittle-like failures. These slit or brittle-like failures were characterized by crack initiation and slow crack growth. The procedure used to rate the strength of plastic pipe did not distinguish between ductile fractures and slit fractures and assumed that both types of failures would be described by the same straight line.

The assumption of ductility of plastic piping had important safety ramifications. For example, a number of experts believed it was safe to design plastic piping installations based on stresses primarily generated by internal pressure and to give less consideration to stress intensification generated by external loading. Ductile material reduces stress intensification by localized yielding, or deformation.

As noted previously, laboratory data supported the strength rating assigned to DHDA 2077 Tan resin by the process used at the time to rate strength; nevertheless, the material showed evidence of early ductile-to-brittle transition. The fact that the process used to measure the long-term durability of piping materials did not reveal the susceptibility to premature brittle-like cracking of the DHDA 2077 Tan material highlights the weaknesses of the process in use at the time. More significantly, it calls into question the durability of other early materials that were rated using the same process and that remain in service today. This concern is heightened by the fact that, in addition to the Waterloo accident involving Century pipe and DHDA 2077 Tan resin, other accidents investigated or documented by the Safety Board have demonstrated that brittle-like cracking occurs in other older plastic piping as well.

All available evidence indicates that polyethylene piping's resistance to brittle-like cracking has improved significantly through the years. Several experts in gas distribution plastic piping have told the Safety Board that a majority of the polyethylene piping manufactured in the 1960s and early 1970s had poor resistance to brittle-like cracking, while only a minority of that manufactured by the early 1980s could be so characterized.[17] Several gas system operators have told the Safety Board that they are aware of no instances of brittle-like cracking with their own modern polyethylene piping installations.

Premature brittle cracking in plastic piping is a complex phenomenon. Without clear and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Frequently, piping manufacturers, because they can receive feedback from a number of customers, are the first to learn of systemic problems with their products. For small operators, contact with a manufacturer may be the major source of outside communication about poorly performing products. Unfortunately, while manufacturers have a high degree of technical expertise regarding their products, they may also tend to aggressively publicize the best performance characteristics of their products while only reluctantly acknowledging weaknesses. The Safety Board is aware of only a very few cases in which manufacturers of resin or pipe have formally notified the gas industry of materials having poor resistance to brittle cracking.

Thus, although reputable manufacturers commonly provide essential technical assistance and serve as partners to pipeline operators, operators are still responsible for evaluating and determining which products are most likely to maintain the integrity of their pipeline systems. Furthermore, perhaps because the possibility of premature failure of plastic piping due to brittle-like cracking has not been fully appreciated within the industry and the scope of the potential problem has not been fully measured, the Federal Government has not provided information on this issue to gas system operators. The Safety Board concluded that gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping.

In the view of the Safety Board, manufacturers of resin and pipe should do more to notify pipeline operators about the poor brittle-crack resistance of some of their past products. The Plastics Pipe Institute (PPI) is the manufacturers' organization that covers most of the major resin and pipe producers, many of whom have manufactured resin and pipe for several years. The Safety Board therefore recommended that the PPI advise its members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure.

---

[17]A number of these experts considered material to have poor resistance to brittle-like cracking if the material was shown to have brittle-like fractures in stress rupture testing at 73 °F before 100,000 hours.

Based on evidence examined by the Safety Board, the premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which undamaged piping is subjected to stress intensification generated by external forces. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of piping with poor resistance to brittle-like cracking and external forces can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concluded that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects. The Safety Board special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

Subsequent to the Waterloo accident, personnel from the Iowa Department of Commerce, after discussions with OPS personnel, stated that the Waterloo installation was not in violation of 49 CFR 192.361, which specifies minimum pipeline safety standards for the installation of gas service piping. They further stated that, while they agree that the installation of protective sleeves at pipeline connections is prudent, a specific requirement to install protective sleeves is beyond the scope of Part 192 and is inconsistent with the regulation's performance orientation.

The Transportation Safety Institute (TSI) conducts training classes for Federal and State pipeline inspectors. TSI instructors advise class participants that many of the performance-oriented regulations within Part 192 can only be found to be violated if the gas system fails in a way that demonstrates that the regulation was not followed. The TSI acknowledges the difficulty of identifying violations under paragraph 192.361(d). A TSI instructor told the Safety Board that, in the case of the failed pipe at Waterloo, the installation could not be faulted under Part 192 because of the length of time (23 years) between the installation date and the failure date.

RSPA acknowledges that the regulation that requires gas service lines to be installed so as to minimize anticipated piping strain and external loading lacks performance measurement criteria. The Safety Board pointed out in a previous accident investigation report[18] that, although

---

[18]National Transportation Safety Board Pipeline Accident Report, *Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16, 1988 to March 29, 1989* (NTSB/PAR-90/03).

the OPS considers many of its pipeline safety regulations to be performance-oriented requirements, many are no more than general statements of required actions that do not establish any criteria against which the adequacy of the actions taken can be evaluated. The Safety Board has further stated that regulations that do not contain measurable standards for performance make it difficult to determine compliance with the requirement. The Safety Board therefore previously recommended that RSPA:

> Evaluate each of its pipeline safety regulations to identify those that do not contain explicit objectives and criteria against which accomplishment of the objective can be measured; to the extent practical, revise those that are so identified. (P-90-15)

As a result of this safety recommendation, the OPS asked the National Association of Pipeline Safety Representatives liaison committee to review the 20 regulations deemed to be the least enforceable due to lack of clarity. The Safety Board has encouraged RSPA to make such a review a periodic effort so that all of the regulations, not just the specified 20, are continually clarified. The last correspondence to the Safety Board from the OPS regarding this recommendation was on March 8, 1993, and the recommendation has remained classified "Open—Acceptable Response." In an October 31, 1997, letter to the OPS, the Safety Board inquired as to the status of 28 open safety recommendations to RSPA, including P-90-15. The OPS has not yet provided a written response for P-90-15. The Safety Board will continue to follow the progress and urge completion of this recommendation.

Federal regulations require that gas pipeline system operators have in place an ongoing program to monitor the performance of their piping systems. Before the Waterloo accident, Midwest Gas developed only a limited capability for monitoring and analyzing the condition of its gas system. For example, the company did not statistically correlate failure rates to the amounts of installed pipe or components provided by specific manufacturers. The design of the program meant that the relatively few areas with high failure rates (for example, those with Century pipe) were aggregated with and therefore masked by the large number of plastic piping installations that had low failure rates. Thus, the Midwest Gas surveillance program did not reveal the high failure rates associated with Century pipe. Only after the accident did Midwest Gas identify the Century pipe within its pipeline system as having high failure rates, even though the company could have collected and processed the same type of data and reached the same determination before the accident. If Midwest Gas had further correlated its data to years of installation, it may have also been able to examine the effects of its changing installation methods or changes in performance with different manufacturers through the years.

The Safety Board concluded that, before the Waterloo accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history. The Safety Board further concluded that if, before the Waterloo accident, Midwest Gas had had an effective surveillance program that tracked and identified the high leakage rates associated with Century piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.

Since the accident, MidAmerican Energy has revised its systems, adding parameters to provide the company with added capability to sort failures. However, MidAmerican Energy has not chosen parameters that will allow an adequate analysis of its plastic piping system failures and leakage history. For example, the generic "improper installation" is a parameter to be linked to leaks; however, no parameters have been added for the presence, lack, improper design, or improper placement of a protective sleeve. And no parameters have been added to link leaks to squeeze locations, improper joining, or items to differentiate between insufficient support and excessive installed bending. The Safety Board therefore concluded that MidAmerican Energy's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.

In a previous accident investigation report,[19] the Safety Board pointed out that many operators had not established procedures to comply with Federal regulations requiring surveillance and investigation of failures. The Safety Board recommended that RSPA:

> Emphasize, as a part of OPS inspections and during training and state monitoring programs, the actions expected of gas operators to comply with the continuing surveillance and failure investigation, including laboratory examination requirements. (P-90-14)

In a letter to the Safety Board, RSPA responded that the TSI had increased emphasis on gas surveillance and failure investigation in the operations block of its industry seminars held across the country. The letter stated that the TSI would incorporate a discussion of accident analysis into a new hazardous liquids seminar that was to be presented for the first time in FY 1992. Additionally, RSPA noted that it planned to place additional emphasis on continuing surveillance and failure investigation requirements in its new inspection forms at the time of the next revision. Based on this response, the Safety Board classified Safety Recommendation P-90-14 "Closed—Acceptable Action."

Despite the RSPA response to this safety recommendation, for a variety of reasons—including the inadequate performance monitoring programs found at Midwest Gas/MidAmerican Energy, the susceptibility to brittle cracking of much of the polyethylene piping installed through the early 1980s, deficiencies noted in gas industry communications regarding poorly performing brands of polyethylene piping, and differences noted in the performance of different types and brands of polyethylene piping—RSPA may need to do more. Gas system operators may need to be advised once again of the importance of complying with Federal requirements for piping system surveillance and analyses. As is the case with older piping, an effective plastic pipeline surveillance program would be based on factors such as piping manufacturer, installation date, pipe diameter, operating pressure, leak history, geographical location, modes of failure (such as bending,

---

[19]National Transportation Safety Board Pipeline Accident Report--*Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16, 1988, to March 29, 1989.*

inadequate support, rock impingement, or improper joining), location of failure (such as at the main to service or at pipe squeeze locations), and other factors such as the presence, absence, or misapplication of a sleeve. An effective program would also evaluate past piping and components installed, as well as past installation practices, to provide a basis for the replacement, in a planned, timely manner, of plastic piping systems that indicate unacceptable performance.

The expressed purpose of RSPA's *Guidance Manual for Operators of Small Natural Gas Systems* is to assist nontechnically trained persons who operate small gas systems. However, the manual provides no caution against bending close to a plastic service connection to a steel main. The manual recommends following manufacturers' instructions and indicates that a properly designed sleeve should be used at this connection, which would address designing the sleeve with the proper diameter and length. However, none of the steel tapping tee manufacturers has recommended precautions to limit stresses at the service to main connection; therefore, nontechnically trained persons may not realize the importance of determining these parameters.

The National Transportation Safety Board therefore makes the following safety recommendations to the Research and Special Programs Administration:

> Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance. Require these operators to develop a plan to closely monitor the performance of this piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-1)

> Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

> Immediately notify those States and territories with gas pipeline safety programs of the susceptibility to premature brittle-like cracking of much of the plastic piping manufactured from the 1960s through the early 1980s and of the actions that the Research and Special Programs Administration will require of gas system operators to monitor and replace piping that indicates unacceptable performance. (P-98-3)

> In cooperation with the manufacturers of products used in the transportation of gases or liquids regulated by the Office of Pipeline Safety, develop a mechanism by which the Office of Pipeline Safety will receive copies of all safety-related notices, bulletins, and other communications regarding any defect, unintended

deviation from design specification, or failure to meet expected performance of any piping or piping product that is now in use or that may be expected to be in use for the transport of hazardous materials. (P-98-4)

Revise the *Guidance Manual for Operators of Small Natural Gas Systems* to include more complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should address pipe bending limits and should emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-5)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

Please refer to Safety Recommendations P-98-1 through -5 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-6

Dr. Steven D. Ban
President and Chief Executive Officer
Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

service line to a plastic main.[4] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[5] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[6] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[7] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[8] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[9] The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged

[4]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[5]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[6]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[7]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[8]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[9]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

automobiles.[10] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[11] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[12] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[13]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[14] The Safety Board's investigation determined that a chemical reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

The procedure used in the United States to rate the strength of plastic pipe, which was developed in the early 1960s, involved subjecting test piping to different stress values and recording how much time elapsed before the piping ruptured. The stress rupture data of the samples were then plotted, and a best-fit straight line was derived to represent the material's decline in rupture resistance as its time under stress increased.

To meet the requirements of the procedure, at least one tested sample had to be able to withstand stress rupture testing until at least 10,000 hours, or slightly more than 1 year. The straight line that was plotted to describe the data for this material was extrapolated out by a factor of 10, to 100,000 hours (about 11 years). The point at which the sloping straight line intersected the 100,000-hour point indicated the appropriate hydrostatic design basis for this material.

A key assumption characterized the assignment of a hydrostatic design basis under the procedure: The procedure assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would continue to be described by a straight line.

---

[10]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[11]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[12]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[13]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[14]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

In the early 1960s, the industry had had little long-term experience with plastic piping, and a straight line seemed to represent the response of the material to laboratory stress testing. With little other information on which to base strength estimations, the straight-line assumption appeared valid. This procedure and assumption for rating the strength was incorporated into industry and government requirements.

As experience grew with plastic piping materials and as better testing methods were developed, however, the straight-line assumptions of the procedure came to be challenged. Elevated-temperature testing indicated that polyethylene piping can exhibit a decline in strength that does not follow a straight line path, but instead is described by a downturn. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours.

The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping much more reliable. Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concluded that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

Another important assumption of the design protocol for plastic pipe involved the ductility of the materials. It was assumed, based on short-term tests, that plastic piping had long-term ductile properties. Ductile material, by bending, expanding, or flexing, can redistribute stress concentrations better than can brittle material, such as cast iron. Notable from results of tests performed under the strength-rating procedure was that those short-term stress ruptures in the testing process tended to be characterized by substantial material deformation in the area of the rupture. This deformation described a material with obvious ductile properties. However, it was shown that, as time-to-failure increased in stress rupture tests, failures in several materials occurred as slit failures that, because they were not accompanied by substantial deformation, were more typical of brittle-like failures. These slit or brittle-like failures were characterized by crack initiation and slow crack growth. The procedure used to rate the strength of plastic pipe did not distinguish between ductile fractures and slit fractures and assumed that both types of failures would be described by the same straight line.

The assumption of ductility of plastic piping had important safety ramifications. For example, a number of experts believed it was safe to design plastic piping installations based on stresses primarily generated by internal pressure and to give less consideration to stress intensification generated by external loading. Ductile material reduces stress intensification by localized yielding, or deformation.

Based on evidence examined by the Safety Board, the premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which undamaged piping is subjected to stress intensification generated by external forces. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of piping with poor resistance to brittle-like cracking and external forces can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concluded that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

Premature brittle cracking in plastic piping is a complex phenomenon. Without clear and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Over a number of years, the GRI sponsored research projects investigating various tests and performance characteristics of polyethylene piping materials. Among these projects was a series of research investigations directed at exploring the fracture mechanics principles behind crack initiation and slow crack growth. These investigations led to the development of slow crack growth tests. The research studies frequently identified the piping and resins studied by codes rather than by specific materials, manufacturers, or dates of manufacture. In 1984, the GRI published a study[15] that compared and ranked several commercially extruded polyethylene piping materials produced after 1971. This study also included several stress rupture curves showing early transitioning from ductile to brittle failure modes. Again, the materials tested were identified by codes.

In short, the GRI has developed a significant amount of data on older plastic piping, but it has frequently published the data in codified terms. Without a way to associate codes with specific products, the average gas pipeline operator could not make effective use of the data.

The National Transportation Board therefore makes the following safety recommendation to the Gas Research Institute:

---

[15]Cassady, M. J., Uralil, F. S., Lustiger, A., Hulbert, L. E., *Properties of Polyethylene Gas Piping Materials Topical Report (January 1973 - December 1983)*, GRI Report 84/0169, Gas Research Institute, Chicago, IL, 1984.

Publish the codes used to identify plastic piping products in previous Gas Research Institute studies to make the information contained in these studies more useful to pipeline system operators. (P-98-6)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-6 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-7 through -9

Mr. Rich Gottwald
Executive Director
Plastics Pipe Institute
1801 K Street, N.W.
Suite 600K
Washington, D.C. 20006-1301

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

service line to a plastic main.[4] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[5] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[6] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[7] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[8] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[9] The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged

---

[4]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[5]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[6]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[7]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[8]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[9]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

automobiles.[10] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[11] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[12] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[13]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[14] The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

Excavations following the Waterloo, Iowa, accident uncovered, at a depth of about 3 feet, a 4-inch steel main.[15] Welded to the top of the main was a steel tapping tee. Connected to the steel tee was a 1/2-inch plastic service pipe. Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred

---

[10]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[11]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[12]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[13]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[14]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

[15]For more information, see Pipeline Accident Brief in appendix to National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service.*

between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate a greater susceptibility to brittle-like cracking under the test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[16] characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking.

The Safety Board has investigated two other pipelines accidents, one in Nebraska in 1978 and one in Minnesota in 1983, that involved Century piping. The Safety Board is also aware of four other accidents that it did not investigate that involved the same brand of piping.

The Century pipe involved in the Waterloo accident was made from Union Carbide's DHDA 2077 Tan resin. Although Union Carbide's laboratory data supported Union Carbide's claimed strength, the Safety Board's review of the same data showed that the material had an early ductile-to-brittle transition, indicating poor resistance to brittle-like fractures.

As a result of its investigation of the Waterloo accident, the Safety Board made the following safety recommendation to the Research and Special Programs Administration (RSPA)

> Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance, and require these operators to develop a plan to closely monitor the performance of this product and to take any action necessary to ensure that the presence of this piping in a gas system is not now and does not become a threat to public safety. (P-98-1)

As you know, in the early years, the procedure used to rate the strength of plastic piping material assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would continue to be described by a straight line. As you are equally aware, however, elevated-temperature testing has indicated that polyethylene piping can exhibit a decline in strength that does not follow a straight line path, but instead is described by a

---

[16]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981; Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1*, Gas Research Institute Report No. 84/0235.2, 1989; and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings, Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

downturn. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours.

Piping manufacturers have addressed this issue by improving their formulations to delay onset of the downturn in strength. At the same time, the procedure was improved to reflect the fact that elevated-temperature testing, by accelerating the fracture process, provided a good representation of the true long-term strength of the tested material at 73 °F. The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping fairly reliable. Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concluded that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

As a result of this finding, the Safety Board made the following safety recommendation to RSPA:

> Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

Premature brittle cracking in plastic piping is a complex phenomenon. Without clear and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Frequently, piping manufacturers, because they can receive feedback from a number of customers, are the first to learn of systemic problems with their products. For small operators. contact with a manufacturer may be the major source of outside communication about poorly performing products. Unfortunately, while manufacturers have a high degree of technical expertise regarding their products, the Safety Board is aware of only a very few cases in which manufacturers of resin or pipe have formally notified the gas industry of materials having poor resistance to brittle cracking.

Furthermore, perhaps because the possibility of premature failure of plastic piping due to brittle-like cracking has not been fully appreciated within the industry and the scope of the potential problem has not been fully measured, the Federal Government has not provided information on this issue to gas system operators. The Safety Board concluded that gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping. In the view of the Safety Board, manufacturers of resin and pipe should do more to notify pipeline operators about the poor brittle-crack resistance of some of their past products.

Stress intensification has been an element common to many plastic gas pipeline accidents investigated by the Safety Board. Based on evidence examined by the Safety Board, the premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which the piping is subjected to external forces. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of piping with poor resistance to brittle-like cracking and external forces can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concluded that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects. The Safety Board special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The gas service involved in the Waterloo, Iowa, accident was installed with a horizontal bend that was sharper than that recommended by current gas industry guidance recommendations; however, the bend may have been installed in the direction of the residual coil bend. Gas industry recommendations do not address residual bending in the pipe, even though plastic piping is often delivered to job sites in banded coils, which leaves some residual bending in the piping even after the bands are removed. Installing coiled pipe with any necessary bending in the direction of the residual bend may be a good practice to limit stresses. Conversely, bending pipe against the direction of the residual coil bend, even if the resulting bend is in accordance with gas industry recommendations, will induce greater stresses.

The National Transportation Safety Board therefore makes the following safety recommendations to the Plastics Pipe Institute:

> Advise your members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure. (P-98-7)
>
> Advise your plastic pipe manufacturing members to develop and publish recommendations for limiting shear and bending forces at plastic service pipe connections to steel mains. (P-98-8)
>
> Advise your plastic pipe manufacturing members to revise their pipeline bend radius recommendations as necessary to take into account the effects of residual coil bends in plastic piping. (P-98-9)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-7 through -9 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply to refer to: P-98-10

Mr. John H. Frantz
Chairman
Gas Piping Technology Committee
PECO Energy Company
300 Front Street
West Conshohecken, Pennsylvania 19428-2723

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Safety Board investigators contacted representatives of the four principal companies that marketed plastic piping for gas service to determine to what extent plastic piping manufacturers were providing recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees.

Three of these manufacturers had published recommendations addressing these issues. These three manufacturers have historically emphasized heat fusion fitting systems instead of field-assembled mechanical fitting systems. Representatives of these manufacturers indicated that mechanical fittings manufacturers should provide installation instructions covering their systems. Accordingly, one of the manufacturers' published literature referred the reader to the manufacturers of mechanical fittings for installation instructions. Nonetheless, these three major polyethylene pipe manufacturers did, in fact, provide recommendations to limit shear and bending forces, and these recommendations can apply to plastic service connections to steel mains via steel tapping tees.

With respect to the specific issue of limiting bends, DuPont, in January 1970, issued recommendations to limit bends for polyethylene pipe. DuPont/Uponor[4] later published bend radius recommendations that differentiated between pipe segments consisting of pipe alone and those with fusion fittings. The recommendations specified much less bending for pipe segments with fusion fittings; however, DuPont/Uponor did not provide bend limits for mechanical fittings. Two of the other major manufacturers (Phillips Driscopipe and Plexco) provide bend limits and differentiate between pipe alone and pipe with fittings, without specifying the type of fittings. None of the manufacturers' literature discusses bending with or against any residual bend remaining in the pipe after it is uncoiled.

Of these four major polyethylene gas pipe manufacturers, only one had no published recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees. Although that company does not manufacture steel tapping tees with compression ends for attachment to plastic services, it does manufacture pipe that will be attached to steel tapping tees via mechanical compression couplings.

The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

The service involved in the Waterloo, Iowa, accident was installed with a bend at the connection point to the main. The plastic service pipe leaving the tee immediately curved

---

[4]Uponor purchased DuPont's plastic pipe business in 1991.

horizontally. The pipe was cut out and brought into the laboratory, at which time the bend had a measured horizontal radius of approximately 34 inches. Based on field conditions and photos, MidAmerican Energy (the current Waterloo system operator) estimated the original installed horizontal bend radius to have been about 32 inches. This bend is sharper than that allowed by current industry installation recommendations for modern piping adjacent to fittings.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

In its investigation of the previously referenced 1971 accident in Texas, the Safety Board determined that protective sleeves were too short to fully protect a series of service connections to a main. The Safety Board noted that a protective sleeve must have the correct inner diameter and length if it is to protect the connection from excessive shear forces. As a result, and in response to a Safety Board safety recommendation,[5] the 1974 and later editions of the GPTC *Guide for Gas Transmission and Distribution Piping Systems* included guidance that "a protective sleeve designed for the specific type of connection should be used to reduce stress concentrations."

Designing protective sleeves for the specific connection is presumed to include designing the sleeve for the correct inner diameter and length, and may also include positioning the sleeve correctly, since positioning the sleeve affects its effective length. However, if steel tapping tee manufacturers do not address the parameters for sleeve design and positioning, gas pipeline operators may not realize the importance of determining these parameters. The guidance would be much more useful to gas pipeline operators if the GPTC included in the guide a specific statement of the need to design protective sleeves so that they will have the correct inner diameter and length, as well as the need to properly position the sleeves.

The GPTC Guide does not include recommendations to limit bending in plastic piping during the installation of service lines under 49 *Code of Federal Regulations* (CFR) 192.361. Although the Guide references the *A.G.A. Plastic Pipe Manual for Gas Service*, and this manual does provide recommendations on bending limits, the GPTC Guide does not reference this manual in its guidance material under 49 CFR 192.361.

The National Transportation Safety Board therefore makes the following safety recommendation to the Gas Piping Technology Committee:

> Revise the *Guide for Gas Transmission and Distribution Piping Systems* to include complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should emphasize the need to limit pipe

---

[5]Safety Recommendation P-72-64 from National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

bending and should include a discussion of the proper design and positioning of a protective sleeve to limit stress at the connection. (P-98-10)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-10 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-11 and -12

Mr. James A. Thomas
President
American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, Pennsylvania 19428-2959

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

---

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Safety Board investigators contacted representatives of the four principal companies that marketed plastic piping for gas service to determine to what extent plastic piping manufacturers were providing recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees.

Three of these manufacturers had published recommendations addressing these issues. These three manufacturers have historically emphasized heat fusion fitting systems instead of field-assembled mechanical fitting systems. Representatives of these manufacturers indicated that mechanical fittings manufacturers should provide installation instructions covering their systems. Accordingly, one of the manufacturers' published literature referred the reader to the manufacturers of mechanical fittings for installation instructions. Nonetheless, these three major polyethylene pipe manufacturers did, in fact, provide recommendations to limit shear and bending forces, and these recommendations can apply to plastic service connections to steel mains via steel tapping tees.

The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The most recent ASTM standard covering the installation of polyethylene piping (D2774) was revised in 1994. This standard addresses the vulnerability of the point-of-service connection to the main. The standard further recommends the use of a protective sleeve if needed to protect against possible differential settlement. The standard practice additionally advises consultation with manufacturers, which would presumably address designing the sleeve with a proper diameter and length, as well as positioning the sleeve correctly. However, as noted previously, none of the steel tapping tee manufacturers has recommended precautions to limit stresses at the service to main connection; therefore, gas pipeline operators may not realize the importance of determining these parameters.

Currently, manufacturers that provide protective sleeves have their own criteria for designing sleeve lengths and diameters for their fittings. Some manufacturers' criteria are based on limiting stress to a maximum safe value, while one manufacturer has advised the Safety Board that its sleeve is not designed to limit bending, but only to guard against shear forces at the connection point. No standard criteria exist for designing protective sleeves. A published common criteria would better motivate a wider spectrum of manufacturers and gas operators to apply scientific reasoning to their decisions on protective sleeve use. A published common criteria would provide guidance to gas operators who provide their own sleeves rather than using manufacturer-supplied sleeves.

The National Transportation Safety Board therefore makes the following safety recommendations to the American Society for Testing and Materials:

> Revise ASTM D2774 to emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-11)
>
> Develop and publish standard criteria for the design of protective sleeves to limit stress intensification at plastic pipeline connections. (P-98-12)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-11 and -12 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-13

Mr. David N. Parker
President and Chief Executive Officer
American Gas Association
1515 Wilson Boulevard
Arlington, VA 22209

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1]For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by the Research and Special Programs Administration (RSPA). The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive

---

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Safety Board investigators contacted representatives of the four principal companies that marketed plastic piping for gas service to determine to what extent plastic piping manufacturers were providing recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees.

Three of these manufacturers had published recommendations addressing these issues. These three manufacturers have historically emphasized heat fusion fitting systems instead of field-assembled mechanical fitting systems. Representatives of these manufacturers indicated that mechanical fittings manufacturers should provide installation instructions covering their systems. Accordingly, one of the manufacturers' published literature referred the reader to the manufacturers of mechanical fittings for installation instructions. Nonetheless, these three major polyethylene pipe manufacturers did, in fact, provide recommendations to limit shear and bending forces, and these recommendations can apply to plastic service connections to steel mains via steel tapping tees.

The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufacturers steel tees with a compression end for plastic gas service connections. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The service involved in the Waterloo, Iowa, accident was installed with a bend at the connection point to the main. The plastic service pipe leaving the tee immediately curved horizontally. The pipe was cut out and brought into the laboratory, at which time the bend had a measured horizontal radius of approximately 34 inches. Based on field conditions and photos, MidAmerican Energy (the current Waterloo system operator) estimated the original installed horizontal bend radius to have been about 32 inches. This bend is sharper than that allowed by current industry installation recommendations for modern piping adjacent to fittings.

The most recent edition of the *A.G.A. Plastic Pipe Manual for Gas Service*[4] identifies the connection of plastic pipe to service tees as "a critical junction" needing installation measures "to avoid the potentially high...stresses on the plastic at this point." Although the manual recommends proper support and the use of protective sleeves, no guidance is included on the

---

[4] *A.G.A. Plastic Pipe Manual for Gas Service*, American Gas Association, Catalog No. XR 9401, 1994.

importance of a protective sleeve's proper length, diameter, or placement. Instead, the manual includes a sentence recommending that manufacturers' instructions be followed carefully. Such advice presumes that the manufacturers' instructions address designing the sleeve to have the correct inner diameter and length, as well as positioning the sleeve properly, in order to limit the shear and bending forces at the connection. Unfortunately, since none of the steel tapping tee manufacturers recommend any precautions to limit shear and bending forces at the connection point, gas pipeline operators may not realize the importance of determining these parameters.

The manual includes, without elaboration, the following sentence:

> Installation of the tee outlet at angles up to 45° from the vertical or along the axis of the main as a 'side saddle' or 'swing joint' may be considered to further minimize...stresses.

This sentence is subject to different interpretations and does not explain how stresses might be reduced. Moreover, many gas system pipeline operators recognize that installing services 90° from the main helps with future locating of the pipe and reduces the likelihood of excessive bending, which could generate excessive stress. In the view of the Safety Board, this sentence does not provide useful guidance as it is written, and the A.G.A. Plastic Materials Committee would be well advised to either expand on or delete this sentence.

Figure 48 from the *Distribution Book D-2* of the A.G.A.'s GEOP series shows a steel tapping tee with a compression coupling joint connected to a plastic service. The illustration shows a protective sleeve and includes a note to extend the protective sleeve to undisturbed or compacted soil or to blocking. But the figures also show the blocking positioned so that either the edge of the blocking or the edge of the protective sleeve might provide a fixed contact point on the plastic service pipe if the weight of backfill were to cause the pipe to bend down. Additional illustrations within this GEOP Series book show this same positioning of the blocking with respect to the plastic pipe.

The Safety Board notes that ASME B31.8 and ASTM D2774 discourage supporting plastic pipe by the use of blocking. In the view of the Safety Board, these illustrations would provide better guidance if they were revised to eliminate showing the possibility of blocking or other fixed contact point supporting plastic pipe.

The National Transportation Safety Board therefore makes the following safety recommendation to the American Gas Association:

> Revise your *Plastic Pipe Manual for Gas Service* and your *Gas Engineering and Operating Practices* series to provide complete and unambiguous guidance for limiting stress at plastic pipe service connections to steel mains. (P-98-13)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-13 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-14 and -15

Mr. Stanley J. Bright
Chairman, President, and Chief Executive Officer
MidAmerican Energy Corporation
666 Grand Avenue
Post Office Box 657
Des Moines, Iowa 50303-0657

At 10:07 a.m. central daylight savings time on Monday, October 17, 1994, a natural gas explosion and fire destroyed a one-story, wood frame building in Waterloo, Iowa. The force of the explosion scattered debris over a 200-foot radius. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.[1]

Six persons inside the building died, and one person sustained serious injuries. Three persons working in an adjacent building sustained minor injuries when a wall of the building collapsed inward from the force of the explosion. The explosion also damaged nine parked cars. A person in a vehicle who had just exited the adjacent building suffered minor injuries. Additionally, two firefighters sustained minor injuries during the emergency response. Two other nearby buildings also sustained structural damage and broken windows.

The National Transportation Safety Board determined that the probable cause of the explosion and fire was stress intensification, primarily generated by soil settlement at a connection to a steel main, on a 1/2-inch polyethylene pipe that had poor resistance to brittle-like cracking.

Safety Board examination of the fracture surface and failed pipe from the Waterloo accident revealed evidence of stress intensification. For example, the upper portion of the inside of the failed pipe showed the impression of the edge of the tee stiffener, indicating that the top of the pipe had been pressed down. The failure of the pipe can be directly associated with this stressed area, which was characterized by several brittle-like slow crack growth fractures that

[1]For more information, see appendix A (Pipeline Accident Brief of Waterloo, Iowa, accident) to National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

originated on or near the pipe inner wall just outside the depression associated with the tip of the tee stiffener. These slow crack fractures propagated through the wall of the pipe.

The stress intensification noted in the Waterloo pipe was consistent with the pipe's having been subjected to shear and bending forces generated primarily by soil settlement.[2] Soil settlement is a common source of stress intensification for buried plastic pipelines, and it can occur and contribute to a piping failure even though no observable voids are noted during a subsequent excavation. Ultimate settlement of backfill can take many years, and sometimes it only occurs after periods of heavy rains (such as the area experienced the previous year) or under additional external loading (such as that represented by truck traffic over the connection).

The accident investigation could not determine whether the ground settlement at Waterloo occurred because of inadequate compaction and support under the connection at the time it was installed, or whether it occurred despite initial adequate compaction and support. Nor could it be conclusively determined whether the amount of soil settlement was slight and generated relatively low stresses over a long period of time, or whether the soil settlement was large and generated relatively high stresses over a relatively short period of time. Because of these uncertainties, investigators could not determine how much more resistance to crack initiation and slow crack growth the pipe would have needed to have successfully resisted the stresses to which it was subjected.

An examination of MidAmerican Energy's recent construction standards for minimizing shear and bending forces at plastic service connection points to steel mains revealed that MidAmerican Energy had no standard that called for firm compacted support under these connections. MidAmerican Energy connected plastic service pipe to mains with steel tapping tees welded at the factory to factory-joined plastic-to-steel transition fittings. Although MidAmerican Energy designed its own protective sleeves for this application, it did so without a design criteria for length or inner diameter, or for positioning the protective sleeves. Without such criteria, MidAmerican Energy may reduce the sleeve's effectiveness in limiting stress intensification. The Safety Board concluded that, because MidAmerican Energy's gas construction standards do not establish well-defined criteria for supporting plastic pipe connections to steel mains or for designing or installing its protective sleeves at these connections, these standards do not ensure that connections will be adequately protected from stress intensification.

Federal regulations require that gas pipeline system operators have procedures for monitoring gas system failures and leakage histories, analyzing failures, and submitting failed samples for laboratory examination, all intended to help determine the causes of failures so that action can be taken to minimize the possibility of recurrences. Before the Waterloo accident, Midwest Gas developed only a limited capability for monitoring and analyzing the condition of its gas system. For example, the company did not statistically correlate failure rates to the

---

[2]The failed pipe also showed signs that the installed horizontal curve may have generated horizontal bending forces. Other factors contributing to stress at the connection included the pipe's internal pressure and may have included residual stresses inside the wall of the pipe resulting from the manufacturing process.

amounts of installed pipe or components provided by specific manufacturers. The design of the program meant that the relatively few areas with high failure rates (for example, those with Century pipe) were aggregated with and therefore masked by the large number of plastic piping installations that had low failure rates. Thus, the Midwest Gas surveillance program did not reveal the high failure rates associated with Century pipe. Only after the accident did Midwest Gas identify the Century pipe within its pipeline system as having high failure rates, even though the company could have collected and processed the same type of data and reached the same determination before the accident. If Midwest Gas had further correlated its data to years of installation, it may have also been able to examine the effects of its changing installation methods or changes in performance with different manufacturers through the years.

The Safety Board concluded that, before the Waterloo accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history. The Safety Board further concluded that if, before the Waterloo accident, Midwest Gas had had an effective surveillance program that tracked and identified the high leakage rates associated with Century piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.

Since the accident, MidAmerican Energy has revised its systems, adding parameters to provide the company with added capability to sort failures. However, MidAmerican Energy did not chose parameters that will allow an adequate analysis of its plastic piping system failures and leakage history. For example, the generic "improper installation" is a parameter to be linked to leaks; however, no parameters were added for the presence, lack, improper design, or improper placement of a protective sleeve. And no parameters were added to link leaks to squeeze locations, improper joining, or items to differentiate between insufficient support and excessive installed bending. The Safety Board therefore concluded that MidAmerican Energy's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.

An effective surveillance program would include the data base inputs that would allow the company to adequately monitor and characterize the types and causes of plastic piping field failures. The *A.G.A. Plastic Pipe Manual for Gas Service* recommends the use of a form for recording necessary information on plastic piping failures; this form may be helpful to MidAmerican Energy as it decides which data fields would be necessary to provide for an adequate analysis of its plastic piping system failures and leakage history. The *A.G.A. Plastic Pipe Manual for Gas Service* further recommends collecting this information, then performing visual examinations of the type and cause of failure and, in some instances, a laboratory analysis. The above steps may help MidAmerican Energy comprehensively monitor and address parts of its plastic pipeline system—other than those installations with Century pipe—that may also indicate unacceptable performance.

The National Transportation Safety Board therefore makes the following safety recommendations to MidAmerican Energy Corporation:

Modify your gas construction standards to require (1) firm compacted support under plastic service connections to steel mains, and (2) the proper design and positioning of protective sleeves at these connections. (P-98-14)

As a basis for the timely replacement of your plastic piping systems that indicate unacceptable performance, review your existing plastic piping surveillance and analysis program and make the changes necessary to ensure that the program is based on sufficiently precise factors such as piping manufacturer, installation date, pipe diameter, geographical location, and conditions and locations of failures. (P-98-15)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-14 and -15 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply to refer to: P-98-16 and -17

Mr. Richard E. Cota
President
Continental Industries, Inc.
Post Office Box 994
Tulsa, Oklahoma 74101

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property.[1] Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

Excavations following the Waterloo, Iowa, accident uncovered, at a depth of about 3 feet, a 4-inch steel main. Welded to the top of the main was a steel tapping tee, manufactured by Continental Industries, that was connected to a 1/2-inch plastic service pipe. The National Transportation Safety Board determined that the probable cause of the Waterloo natural gas explosion and fire was stress intensification, primarily generated by soil settlement at the connection to the steel main, on a polyethylene pipe service line that had poor resistance to brittle-like cracking. The connection was not covered by a protective sleeve.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel

[1]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

mains is inadequate or ambiguous. The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections.[2] The Safety Board identified and contacted representatives of Continental, Dresser Industries, Inc., Inner-Tite Corporation,[3] and Mueller Company. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

Safety Board examination of a protective sleeve offered by Continental to its customers revealed that the sleeve that did not have sufficient clearance to allow the application of field wrap (intended to protect the steel tee from corrosion after it is in the ground) to that portion of the steel tee under the sleeve. This observation was confirmed by a Continental representative. The Safety Board concluded that the use of Continental tapping tees with the company's protective sleeves thus may leave the tapping tees susceptible to corrosion.

The National Transportation Safety Board therefore makes the following safety recommendations to Continental Industries, Inc.:

> Provide a means to ensure that the use of your protective sleeves with your tapping tees at plastic pipe connections to steel mains does not compromise corrosion protection for the connection. (P-98-16)
>
> Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains. (P-98-17)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

---

[2] J. B. Rombach Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.

[3] Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections, and marketed the complete assembly.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations P-98-16 and -17 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-18

Mr. William E. Bradford
Chairman and Chief Executive Officer
Dresser Industries, Inc.
2001 Ross Avenue
Dallas, Texas 75201

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property.[1] Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections.[2] The Safety Board identified and contacted representatives of Continental

[1]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

[2]J. B. Rombach Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.

Industries, Dresser Industries, Inc., Inner-Tite Corporation,[3] and Mueller Company. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The National Transportation Safety Board therefore make the following safety recommendation to Dresser Industries, Inc.:

> Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains. (P-98-18)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-18 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

---

[3]Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections, and marketed the complete assembly.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply to refer to: P-98-19

Mr. George W. Davis
President
Inner-Tite Corporation
110 Industrial Drive
Holden, Massachusetts 01520

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property.[1] Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections.[2] The Safety Board identified and contacted representatives of Continental

[1] For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

[2] J. B. Rombach Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.

Industries, Dresser Industries, Inc., Inner-Tite Corporation,[3] and Mueller Company. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The National Transportation Safety Board therefore make the following safety recommendation to Inner-Tite Corporation:

> Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains. (P-98-19)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; and P-98-20 to Mueller Company.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-19 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

---

[3]Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections, and marketed the complete assembly.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-20

Mr. Dale B. Smith
President
Mueller Company
500 W. Eldorado Street
Post Office Box 671
Decatur, Illinois 62525

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property.[1] Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

The Safety Board's special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections.[2] The Safety Board identified and contacted representatives of Continental

[1]For more information, see National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

[2]J. B. Rombach Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.

Industries, Dresser Industries, Inc., Inner-Tite Corporation,[3] and Mueller Company. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

The National Transportation Safety Board therefore make the following safety recommendation to Mueller Company:

> Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains. (P-98-20)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-1 through -5 to the Research and Special Programs Administration; P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and 17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; and P-98-19 to Inner-Tite Corporation.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation P-98-20 in your reply. If you need additional information, you may call (202) 314-6469.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman

---

[3] Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections, and marketed the complete assembly.